Announcements

- EXAM 3 will be *this* Thursday!
- Homework for tomorrow…

  Ch. 34: CQ 6, Probs. 12, 18, 20, & 22

  CQ4: a) CW b) no current c) CCW

  33.10: a) 8.7×10^{-4} Tm^2 b) CW

  33.12: 5.0 A, CW

  33.50: a) 6.3×10^{-4} N b) 3.1×10^{-4} W c) CCW, 1.3×10^{-2} A d) 3.1×10^{-4} W
- Office hours…

  MW 10-11 am

  TR 9-10 am

  F 12-1 pm
- Tutorial Learning Center (TLC) hours:

  MTWR 8-6 pm

  F 8-11 am, 2-5 pm

  Su 1-5 pm

Chapter 34

Electromagnetic Fields & Waves

(EM Waves & Properties of EM Waves)

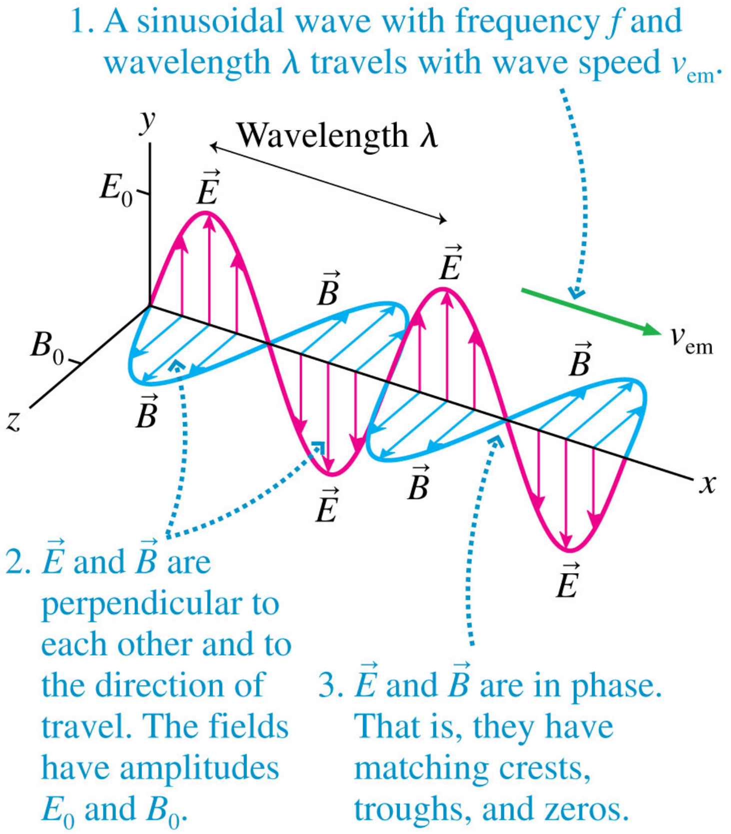
34.5: Electromagnetic Waves

- Faraday speculated that light was connected to electricity & magnetism.
- James Clerk Maxwell, using his electromagnetic (EM) field equations, was the 1st to understand that light is *an oscillation of the EM field*.

Maxwell's equations predict that:

1. EM waves can exist at ANY wavelength, NOT just at the wavelengths of visible light.
2. All EM waves travel in a vacuum with the SAME speed, the speed of light!

34.5: Electromagnetic Waves

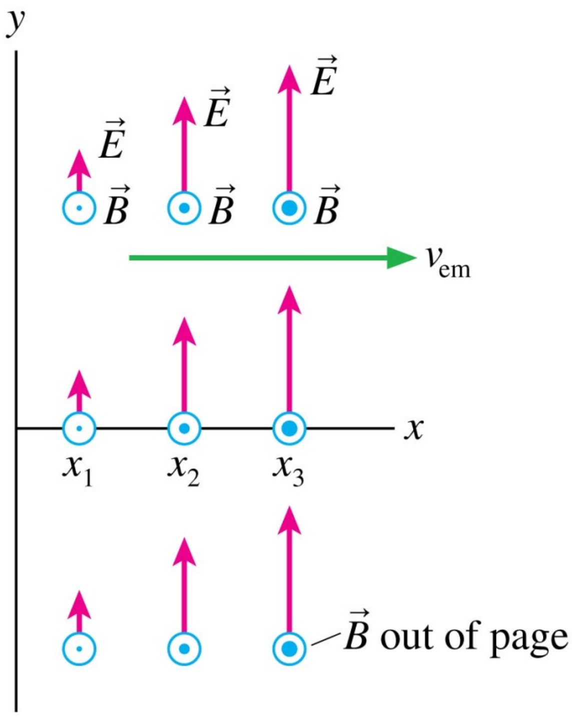


- This figure shows the *E*-field & *B*-field at points along the *x*-axis, due to a passing EM wave.
- The oscillation *amplitudes* are related by:

$$\boxed{E_0 = v_{em} B_0}$$

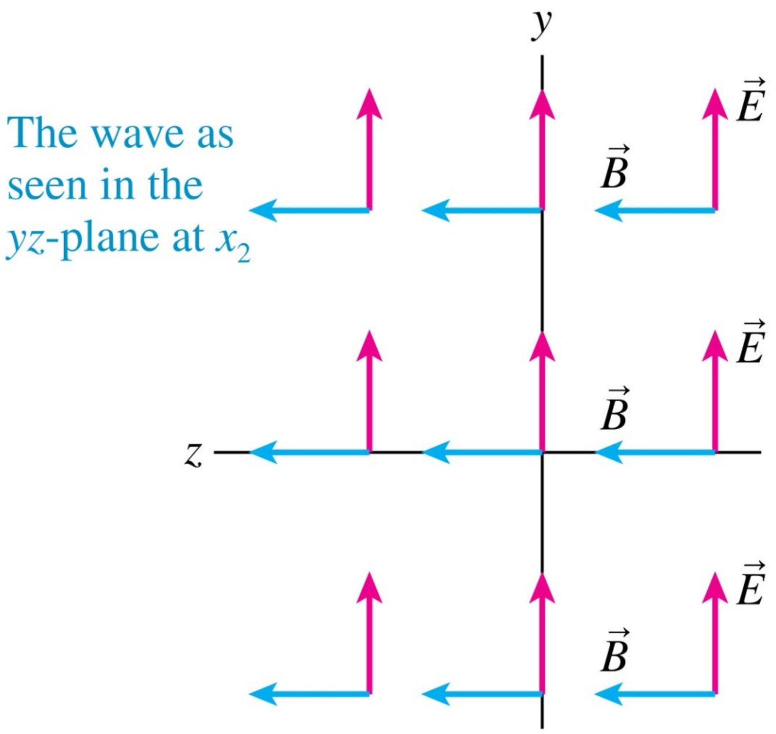
34.5: Electromagnetic Waves

The wave as seen in the *xy*-plane



- The figure shows the fields due to a *plane wave*, traveling to the right along the *x*-axis.
- The fields are the same everywhere in any *yz*-plane perpendicular to *x*.
- This is a small section of the *xy*-plane, at a particular instant of time.

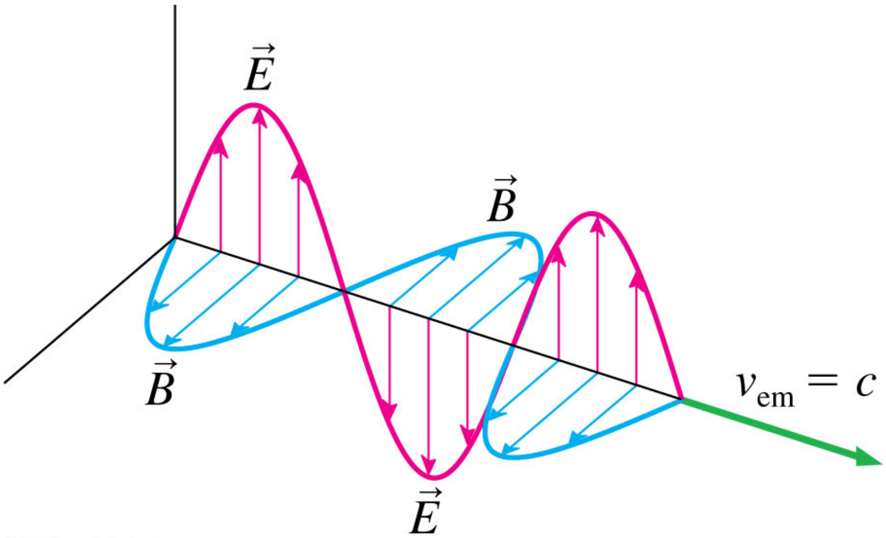
34.5: Electromagnetic Waves



- This figure shows the fields due to a *plane wave*, traveling *toward you*, along the x-axis.
- If you watched a movie of the event, you would see the E-field and B-field at each point in this plane *oscillating* in time, but always synchronized with *all* the other points in the plane.

34.5: Electromagnetic Waves

Maxwell's field equations *predict* EM waves with wave speed:



$$v_{em} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$$

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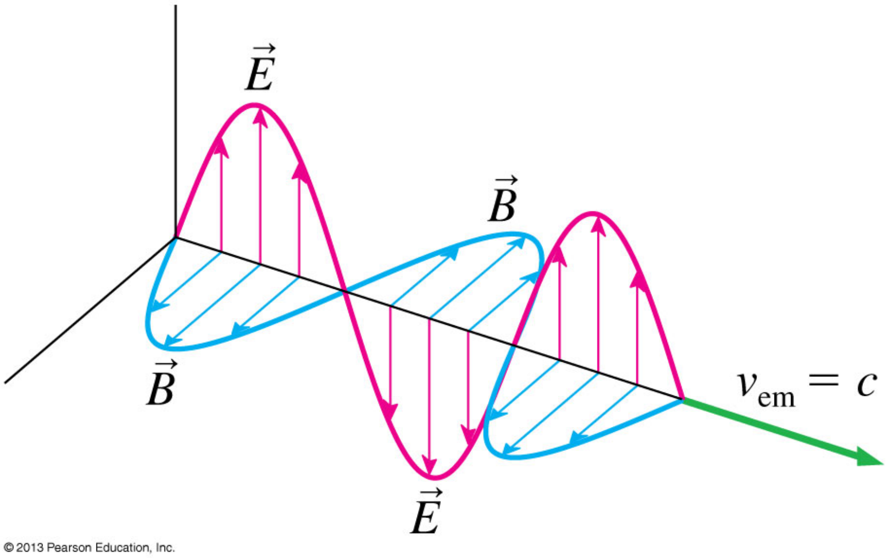


$$v_{em} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \simeq 3.0 \times 10^8 \text{ m/s}$$

34.5: Electromagnetic Waves

Maxwell's field equations *predic*t EM waves with wave speed:

$$v_{em} = \frac{1}{\sqrt{\epsilon_0 \mu_0}} \simeq 3.0 \times 10^8 \ \mathrm{m/s}$$

Notice:

- ε_o and μ_o were determined by the size of *E* and *B* due to point charges and have nothing to do with waves!
- Maxwell's eqns predict that *E*- & *B*-fields can form a *self-sustaining EM wave,* if that wave travels at the above speed!

34.6:
Properties of Electromagnetic Waves

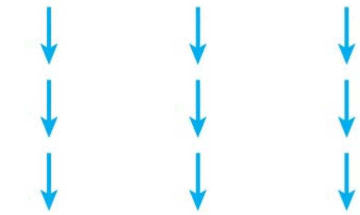
ALL *EM* waves must satisfy four basic conditions:

1. The *E*-fields and *B*-fields are *perpendicular* to the *direction of propagation*. The EM wave is a *transverse wave*.
2. The *E*- and *B*-fields are *perpendicular to each other* in a manner such that $\vec{E} \times \vec{B}$ is in the *direction of the propagation*.
3. The wave travels in vacuum at a speed of
$$v_{em} = 1/\sqrt{\epsilon_0 \mu_0} = c$$
4. $E = cB$ at any point on the wave.

Quiz Question 1

An *EM* plane wave is coming toward you, out of the screen. At one instant, the *E-field* looks as shown.

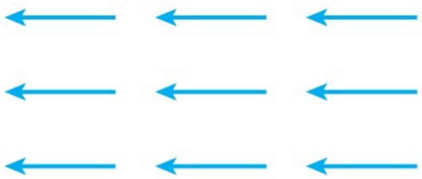
Which is the wave's *B*-field at this instant?



A.

B.

C.

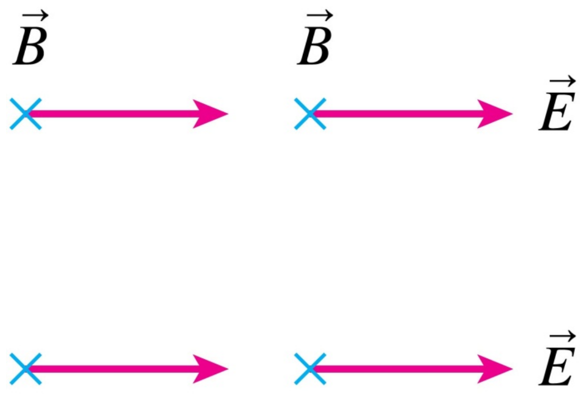


D.

E. The *B*-field is instantaneously zero.

Quiz Question 2

In which direction is this *EM* wave traveling?

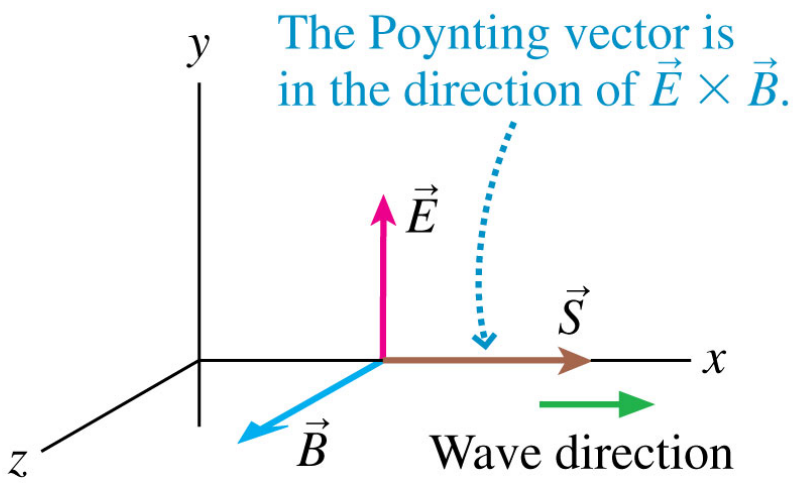


1. Up.
2. Down.
3. Into the screen.
4. Out of the screen.
5. These are not allowable fields for an EM wave.

Energy & Intensity

The energy flow of an *EM* wave is described by the *Poynting vector*, defined by

$$\boxed{\vec{S} \equiv \frac{1}{\mu_0}\vec{E} \times \vec{B}}$$



Notice:

- The *Poynting vector points* in the direction in which the *EM* wave is traveling!
- SI units?

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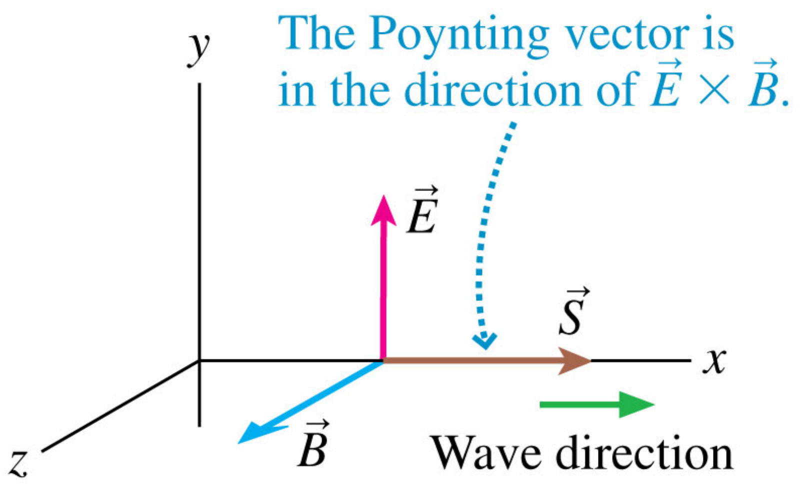

Notice:

- The *Poynting vector points* in the direction in which the *EM* wave is traveling!
- SI units? $[S] = W/m^2$
  - *S* measures the *instantaneous rate of energy transfer per unit area* of the wave.

Energy & Intensity

- The Poynting vector is a function of time, oscillating from 0 to S_{max} and back to 0 *twice* during each period of the wave's oscillation.
- Of more interest is the *average* energy transfer, averaged over one cycle of oscillation, which is the wave's *intensity***.**
- The *intensity* of the *EM* wave is…

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- The *intensity* of the *EM* wave is…

$$\boxed{I = \frac{P}{A} = \frac{1}{2c\mu_0}E_0^2 = \frac{1}{2}c\epsilon_0 E_0^2}$$

Energy & Intensity

- The *intensity* of a wave fall off with distance.

- If a *point source* with power P_{source} emits *EM* waves *uniformly* in all directions, the *EM* wave intensity at distance r from the source is

$$\boxed{I = \frac{P_{source}}{4\pi r^2}}$$